Challenges in Model Transition from SSARR to RESSIM for the Corps of Engineers, Northwestern Division

George Chan Modini [1]

Water Management Division, Northwestern Division plays an important role in the operation of the complex system of multiple-purpose projects in the Pacific Northwest. In the Columbia River Basin, this role includes hydrologic investigations, power system analyses, flood control studies, operational planning, and real time operations. Up until this year, the Corps used the Streamflow Synthesis and Reservoir Regulation Model (SSARR) as an operational hydrology model. The model has served the Corps well for almost 50 years. Streamflow forecasts are generated from SSARR by the National Weather Service River Northwest River Forecast Center (NWRFC). The Corps then provides regulation guidance to SSARR to develop future forecasts of regulated streamflows.

The NWRFC is transitioning from SSARR to the National Weather Service River Forecast System (NWSRFS) model. The model has a strong hydrologic component but lacks the flexibility with respect to reservoir modeling. The Hydrologic Engineering Center (HEC) has developed as part of Corps of Engineers Water Management System (CWMS) modernization a new reservoir model. The new model is called the Reservoir Evaluation and System-Simulation (RESSIM) model. The purpose of this paper is to present a history to date of SSARR, NWSRFS, and RESSIM. This paper will also explore short- and long-term modeling goals.

[1] George Chan Modini, U.S. Army Corps of Engineers, Northwestern Division, 220 NW 8th Avenue, Portland, Oregon 97209, 503-808-3958, george.c.modini@usace.army.mil

Hydrology

The Columbia River Basin is a 259,000 square mile drainage basin which includes a majority of the Pacific Northwest such as the states of Oregon, Washington, Idaho, Western Montana, and some 40,000 square miles in British Columbia (Figure 1). There are over 200 single and multiple purpose dams and reservoir projects. The basin includes portions of Yellowstone, Glacier, Mount Rainier, North Cascades National Parks, the Grand Teton National Park, and the Hells Canyon Wilderness and National Recreational Area. This major river accumulates snow in the winter months and runs off in the early spring and summer. During the runoff, the hydrograph is gradually increasing in nature until the annual peak flow is reached usually during the first half of June. The flood of record, 1894, lasted 50 days. The timing of this runoff is quite unpredictable in nature on a long-range basis due to the many different combinations of meteorological sequences that can occur. Major snowmelt floods are often augmented by rainfall as was the case during the 1948 Vanport Flood. The area of major flood damage in the Columbia River Basin lies along the 140-mile reach of the mainstem below the Bonneville Dam. Protection from this area of flooding is due to a system of levees and reservoirs. For instance, for water year 2002 annual flood damages prevented by levees and reservoirs totaled $590,000,000.

Figure 1. Map of the Columbia River Basin

Historical Perspective

The U.S. Army Corps of Engineers Northwestern Division has played an important role in water resources since it's inception in 1901 for surveying and navigation purposes. With passage of the 1927 Rivers and Harbor Act, development of the Columbia River Basin was initiated through authorized surveys known as "308 Reports". The disastrous 1948 Vanport Flood was the genesis for Corps of Engineers responsibility for system flood control for the Columbia River Basin. This included regional coordination with the Bureau of Reclamation. In 1950, Northwestern Division created Water Management Division, as it is known today, to handle the ever increasing regional coordination of the operation of multi-purpose projects. Purposes include flood control, hydropower, irrigation, navigation, recreation, water supply, and fish and wildlife. For example, regionally, hydropower operations needed to be coordinated with the Bonneville Power Administration to ensure stability of the transmission grid. In addition, many new projects were being designed and built by Districts at a rapid pace within the Division.

Numerous dams, both Federal and private, were constructed. Total storage capacity of the system is about 25 percent of the 156 million acre-feet annual runoff volume as measured at the mouth of the Columbia River. Water Management Division, has and continues to play a key and crucial role in the operation of this complex system of multi-purpose projects. This role involves hydrologic investigations, power system analyses, flood control studies, economic studies, environmental analysis, operational planning, seasonal, and real-time project control. With ratification in 1964 of the treaty between the United States and Canada for the development of the Columbia River, the construction of three storage projects in Canada and Libby project in the United States was assured (Nelson 1971). The last of these projects was built in 1973.

The treaty required development of a flood control operation plan which would integrate operation of reservoirs both in the United States and Canada to achieve a system flood control objective. Water Management Division was given this task and to develop operating criteria based on forecasts of seasonal snowmelt runoff volume and short to long-term day-to-day runoff forecasts of streamflow. These criteria would provide the rules for regulating streamflows on a foresight basis, as a function of both hydrology and reservoir regulation in order to achieve optimum use of flood control storage while meeting all other multi-purpose objectives. There would be two distinct periods with respect to flood control, drawdown and refill. The drawdown period would begin in January and end by April when snow pack would be at maximum. Flood control storage requirements would be a function of forecasted seasonal runoff volume. The reservoirs would then be held at flood control drafts until the spring rise or freshet was determined to have begun and refill would commence. An operational hydrologic model was needed to accomplish this task.

The development of an operational hydrologic model required several steps. Given the unpredictability in snowmelt runoff, the first task of Water Management

Division was given was to study and publish the mechanics of snowmelt hydrology. In the 1950's, this was done by the Snow Investigations Unit in a collaborative effort the the U.S. Weather Bureau, now the National Weather Service. The unit released a snow hydrology report which was at the time the state of the art in snow melt mechanics (Corps of Engineers 1956). It still is referenced today. In addition, seasonal volume runoff forecasts were also developed. These regression based models utilized predictor variables in the form of snow water equivalent, precipitation, runoff. More recent models have also been updated to include the use of climate indexes such as the Southern Oscillation Index (SOI).

Now that the mechanics of snowmelt were understood and seasonal volume runoff forecasts were available, a model to for simulating streamflow and reservoir regulation was needed. A computer model was needed for short- and long-term day-to-day runoff forecasts. Computer program development was initiated in 1956. The model was named the Streamflow Synthesis and Reservoir Regulation model (SSARR). Additionally a hydropower model called the Hydro System Seasonal Regulation Program (HYSSR) was also developed. Coincident with model development, Northwestern Division, as it is known today, purchased the first Corps of Engineers mainframe computer, an IBM 650.

SSARR

The goal of Water Management Division was to develop an operational hydrologic model for use in flood control studies, planning studies, and daily streamflow forecasting. As quoted from the SSARR manual, *" Operational hydrology is becoming more and more dependent on the application of conceptual hydrologic computer models. Limitations in data quality and quantity and in the development of mathematical expressions of the various fundamental relationships prevent the development of an all purpose, theoretically sound model. Thus, there is a need for a model that is conceptually based, yet not so detailed as to prevent its application on a daily basis"* (Corps of Engineers 1987). The model would simulate runoff to include snowmelt and be able to route flows in-river or via reservoirs. With the reservoir regulation model, the user would be able to ingest forecasted inflows or routed flows in the form of a time series, and prescribe various modes of reservoir operation. In addition, with the reservoir model one could assign storage or elevation targets as part of the reservoir operation. The results would be used in hydrologic studies or real time operations. At the time, the model consisted of 67 sub-basins, 47 channel reaches, 28 reservoirs, and 68 downstream control points.

It should be noted that the computational procedures used in SSARR were conceived by Mr. David M. Rockwood, Chief Water Management Branch (Retired) and others. Mr. Rockwood is honored as a Distinguished Civil Servant for Northwestern Division. It is truly amazing that even though Mr. Rockwood retired in the late 1970's, up until this year, SSARR was still being used as an operational model by the Corps. It is a tribute to the robustness of the model and the ingenuity of the Water Management personnel. At the time, nowhere else in the Corps of

Engineers was there an office that combined streamflow forecasting and reservoir regulation as an operational hydrologic model.

The application of SSARR to the Columbia Basin would involve daily simulations of streamflows each year beginning in April after the reservoirs had been drafted during the drawdown period to provide flood control storage. During this refill period, the model would be run on a daily basis if needed to assure the danger of flooding had passed and the reservoirs had refilled. With the SSARR model, a modeler could model normal and maximized temperature sequences as much as 90 days into the future. The flexibility of the model cannot be understated. This feature was very useful in assessing runoff potential and risk. In addition, snow covered area could be determined from the SSARR model because the snow band algorithm utilized a "lumped" method that include elevation bands. In 1963, after model development, that the Corps of Engineers entered into a agreement with the National Weather Service to combine facilities for the development of streamflow forecasting procedures and preparation of operational streamflow forecasts. This was necessary given the monumental task of data collection, model calibration, and information dissemination. This synergistic relationship let to the development of the Columbia River Operational Hydromet System (CROHMS) in 1970. This database is maintained by Water Management Division for use by numerous agencies concerned with water management (Corps of Engineers). Data type include but are not limited to temperature, snow water equivalent, streamflow, water quality, reservoir data. It has become a crucial component in the operation of the Columbia River System. Many regional entities depend on and utilize the CROHMS data system.

Water Management Division now had the data and operational model for hydrologic studies and real time operations. Water Management Division set about the task of developing principles and criteria for a system flood control operation plan based on the final configuration of Columbia River Treaty Project development (Corps of Engineers 1999). Studies for the plan were initiated in 1967 and completed in 1972. The last treaty project, Libby was in operation by 1973. The flood control operation plan was put into use the following year in a major flood in the spring of 1974.

SSARR continued to serve Northwestern Division in Columbia River Basin real time operations until water year 2003. In 2003, the National Weather Service River Forecast Center Office in Portland Oregon, turned off the SSARR model and transitioned to the National Weather Service River Forecast System Model (NWSRFS). Northwestern Division still uses SSARR for hydrologic engineering studies. A graphical user interface (GUI) was developed to work with SSARR in 1992. The GUI is called AUTOREG. The GUI automates input requirements and makes iterative executions of the SSARR program to achieve Columbia River regulation objectives. AUTOREG, incorporates an algorithm for performing a system flood control operation. It also includes options for variable draft limit, low flow limits, and minimum flow requirements as related to Endangered Species Act requirements. Currently the model utilizes a 60-year daily streamflow database.

With the use of AUTOREG, changes to local and system flood control could be evaluated relatively quickly and efficiently. It currently operates on a Sun workstation.

Additionally portions of the SSARR model are used in the National Weather Service River Forecast System (NWSRFS). Additionally, Quebec Hydro in Canada uses SSARR for operational hydrology. SSARR routing criteria are also part of the Hydrologic Engineering Center (HEC) reservoir regulation models, HEC-5 and it's successor Reservoir Evaluation System-Simulation (RESSIM). The SSARR snow band algorithm is also being used by the Cold Regions Lab (CRREL) of the Engineering Research and Development Center (ERDC) in a collaborative effort with HEC in the development of a Distributed Snow Process Model (DSPM) (Daly 1999) with the intent for use with the Hydrologic Modeling System (HEC-HMS), the successor to HEC-1.

Water Management Division has been on the cutting edge of technology for many years. It became a model for water management. SSARR has played an integral role in this success. The Corps has performed work in the Mekong Delta. Many countries have visited Water Management to see first hand a successful water management operation on a regional scale. As recently as 2003, a delegation from Nigeria visited Water Management and various districts and projects and were amazed at how a complex system with all the objectives and constraints operates day in and day to meet all multiple purposes.

NWSRFS

The Northwest River Forecast Center (NWRFC) is one of 13 National Weather Service hydrologic centers in the United States. It works with water management agencies such as the U.S. Army Corps of Engineers, Northwestern Division. Up until water year 2003, the NWRFC, utilized SSARR to simulate long-term streamflow forecasts in the Columbia River Basin. NWSRFS was already being utilized for the short-term component. NWSRFS is a collection of hydrologic models and procedures for forecasting short- and long-term streamflows. The push for NWSRFS model development in the Columbia River Basin was part of a national effort to modernize hydrologic services.

The push for modernizing hydrologic services was related to resources and technology. Maintenance of SSARR was limited due to the small resource pool available consisting of one retired Corps of Engineers employee. SSARR is a non-continous model that requires a lot of manual data input. Over 20,000 pieces of data were processed for a typical model run. On the other hand, the NWSRFS model is a continous model that takes advantage of automatic data input and the latest in hydrologic model development. The National Weather Service felt it was also important to have a nationally supported modeling system (National Weather Service 1996). Primary differences are listed Table 1. In theory utilizing NWSRFS to it's fullest capabilities would enable the NWRFC to focus in improving forecasting techniques through future model development. Some of the work in development phase include distributed modeling and the use of long-lead climate outlooks in streamflow forecasting.

Table 1. Primary Differences Between SSARR and NWSRFS

SSARR	**NWSRFS**
Non-continous	Continous
Manual mean areal precipitation and temperature	Automatic mean areal precipitation and temperature
Manual data input	Automatic Data Input
"Sponge" analogue	"Series of buckets"
Phase routing	Unit Hydrograph
Single elevation zone	Multiple elevation zones
Uniform snow condition	Snow Water Equivalent Accounting

Even though SSARR was no longer used, the NWSRFS model still utilizes many components of the SSARR model. The SSARR routing and reservoir regulation models are used. The reservoir is a simple model that includes the options to specify storage or elevation targets at a project but not control point. Other models not part of SSARR include the Anderson Snow model, the Sacramento Soil Moisture Accounting Model, Consumptive use, ESP and others. A full list is presented in Table 2.

Table 2. National Weather Service River Forecast System (NWSRFS) Models

Snowmelt Models	Andersen Snow Model
Rainfall/Runoff Models	Sacramento Soil Moisture Accounting Model Xinanjiang Soil Moisture Accounting Model NWS RFC API Models
Temporal Distribution of Runoff	Unit Hydrograph
Channel Losses or Gains	Simplified Loss/Gain Model
Channel Routing Models	Lag and K, Muskingham Coefficient, Tatum, Dynamic Wave, SSARR Cascade Routing
Reservoir Regulation	Reservoir Operations Model SSARR Reservoir Operation
Adjustment Procedures	Simplified Flow Adjustment and Blend Model
Stage/Discharge Conversion	Rating Curve Lookup
Time Series Manipulations	Computation of Mean Discharge Weighted Time Series
Plot Displays	Instantaneous/Water Year Plot
Statistical Functions	Calibration, Operation, and ESP Statistics Package

The NWSRFS system consists of calibration (CS), operational forecast OFS), and ensemble streamflow prediction (ESP) systems (Figure 2). Basins were calibrated by developing historical precipitation and temperature time-series and optimized on the model parameters. Operational forecasts (10 days) are made using the calibrated models in conjunction with real-time observed and short-term meteorological forecasts. The ESP model can then be run with historical precipitation and temperature time-series in the ESP system to generate historical conditional hydrographs or probabilistic long-term traces (45-120 days) (National Weather Service 1996).

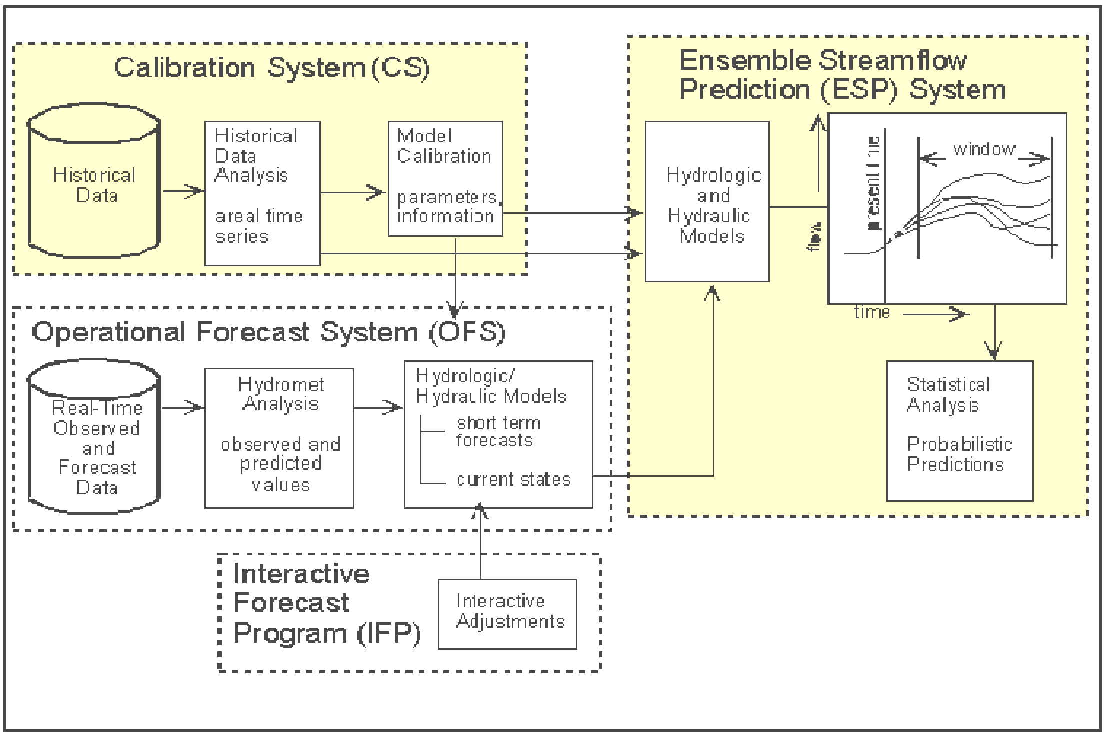


Figure 2. National Weather Service River Forecast System (NWSRFS)

At present there is concern regarding the efficacy of ESP. This occurs in three areas. First, the reservoir regulation model in NWSRFS is somewhat inflexible. Second, there are concerns regarding snow states in the model. Third, there are data exchange issues.

The reservoir regulation model in NWSRFS can only apply one regulation for all ESP generated hydrographs or traces. This presented a problem trying to model reservoir operations for the Columbia River Basin. For example, system objectives and to an extent local objectives are a function of forecasted runoff volume or forecasted runoff distribution. Therefore a proposed operation (regulation) for a specified purpose may or may not work depending on the ESP hydrograph or trace used. This because the ESP hydrograph or trace will produce different runoff volumes or runoff distribution depending on the historical meteorological data used. Since only one regulation file can be used, model output in terms of regulated flow and statistical analysis of the output would not be useful.

Additionally, the short term forecasted meteorological parameters can drastically effect long-term forecasts due to the impact to snow states. Temperature and precipitation are utilized in developing operational forecasts short- and long-term. Temperature forecasts are statistically derived and are generated for a 10-day sequence (maximum and minimum) in 6 hour time steps. Quantitative precipitation forecasts for days 0-3 and 4-10 are also used also in 6 hour time steps. It is the precipitation forecasts that can really effect long-term flow forecasts. For example, the introduction of a rain storm in the 10-day sequence can have an effect on future snow states and therefore long-term streamflow forecasting. Accumulated runoff from one ESP run to the next, could vary a significant amount. This could present problems with respect to water management operations and decision making. With SSARR, the NWSRFC and the Corps were able to make adjustments to snow states and could track accumulated runoff, and make the necessary adjustments rather efficiently. Comparisons were easily made with respect to forecasted runoff volumes (via regression methods) and accumulated runoff volumes via a conceptual model (SSARR). With NWSRFS however, the initial process of model calibration was optimized based on observed streamflow rather than on snow observations. Therefore the effect to snow states was not necessarily accounted.

The NWRFC performed studies on runoff volume as compared to observed volume and it became apparent NWSRFS needed some adjustments. Significant differences in volume also resulted based on the time interval used. It also became apparent that the 50 percent exceedence trace, although not expected to match a most probable regression based forecast, could be drastically different. In response, the NWSRFC has developed a Snow Estimation and Updating System (SEUS) which will permit snow observations to be incorporated to update models as was the case with SSARR (Bissell 1996). In the meantime, the NWRFC has developed a single trace procedure (STP) to serve as an interim procedure until ESP issues are resolved. This trace is similar to the long-term hydrologic trace that was produced with SSARR. STP utilizes historical mean areal precipitation and temperature time series to generate a single long-term hydrologic trace. However since the trace is based on means of historical precipitation and temperature, it is in a sense an average hydrograph with very little resolution.

In the future, the strengths of the NWSRFS will provide more flexibility than SSARR. Recall With SSARR model, a modeler could model normal and maximized hydro meteorological sequences as much as 90 days into the future. With respect to flood control operations, this feature was very useful in assessing runoff potential and risk. The SSARR model utilized a normal and maximized temperature sequences, both with a wet bias in order to account for the effects of precipitation. The strength of NWSRFS is that forecasted and historical precipitation and temperature sequences can both be used. For a headwater basin such as on the Clearwater River above

Dworshak reservoir, one will have not only a short-term deterministic forecast of 10-days but will have long-term historical conditional stream flow hydrographs and the associated conditional probabilistic traces based on historical future precipitation and temperature.

From an information management perspective many issues arise. One, given the rapid development of technology and security issues, there is a bottle neck when trying to sending and receiving forecasts. Two, the amount of hydrographs and traces available for use could be overwhelming. However with the right models (RESSIM) and planning tools, processing of the forecasts can be made efficiently and enable the water resources manager to make a more informed decisions.

RESSIM

The Hydrologic Engineering Center (HEC) of the Corps of Engineers, in Davis, CA has developed a new reservoir regulation model as part of Corps of Engineers Water Management System (CWMS) modernization.   The next generation (NEXGEN) software program is called the Reservoir Evaluation and System-Simulation (RESSIM) model.   The program is the planned successor to the predecessor and highly successful reservoir regulation model, HEC-5.

Water Management Division has both short- and long-term goals with respect to RESSIM model development. Short-term, Water Management Division intends to develop a Columbia River Reservoir Basin simulation model to be used for real time operations. Long-term, it is hoped that Water Management will be able to continue to improve the model for use in planning and flood control studies. This would be especially true as additional features of RESSIM are available such as optimization tools and in-house utilities are converted to work with RESSIM and CWMS.

Short-Term

The short-term focus is to get a simple reservoir regulation model of the Columbia River Basin up and running that can be tested and used in real time operations. Good progress is being accomplished. As of today, Water Management has a basic working model of the Columbia River Basin. The model consists 153 channel reaches, 46 reservoirs, and 199 common computation points.

The work consisted of obtaining a sample dataset and building the model. A dataset generated from the NWSRFS Columbia River Basin model was provided by the NWRFC consisting of a conditional fifty percent execeedence traces and conditional historical hydrographs for April-July for water year 2002 for test simulations. Model development consisted of creating a watershed, reservoir network, entering physical data, and defining reservoir operations. Existing NWSRFS and SSARR models were used as a resource for model data and configuration. The basic steps are presented in the Table 3 courtesy of HEC.

Table 3. RESSIM Model Development

Creating a Watershed	Selecting a configuration Adding elements-Reservoirs, Reaches, Junctions, Diversions
Entering Physical Data	Rating Curves-Junctions Routing Parameters-Reaches Storage Capacity, Outlet Capacity, Losses-Reservoir
Defining Reservoir Operations	Storage Zones, Rules, Downstream Control
Creating Model Alternatives for Testing	Select Reservoir Networks Prepare Historical Data Sets
Perform Model Simulations	Calibration Verfication
Model Adjustments	Calibration Verfication
Data Exchange/Modeling Process	Between NWS and Corps of Engineers
Trial Operational Runs	Sub-basins Entire System

Watershed setup included definition, stream alignment, and configuration (Figure 3). The watershed was defined with help from the NWRFC office. It was decided to keep the naming conventions used by the RFC during watershed setup for efficiency and consistency purposes. The watershed as defined is the entire Columbia River Basin from the headwaters to river mile 0.0. In keeping with the collaborative relationship, the NWRFC provided shape files from the ARC Info utility. These shape files are easily ingested by RESSIM in the form of layers and contain the same information utilized when calibrating the NWSRFS Columbia Basin Model. RESSIM model layers include rivers, lakes, reservoirs, inflow forecast points, local forecast points, USGS gauges, major river basins, snow collection and SNOTEL data sites. Many of these layers can be used for other CWMS capabilities.

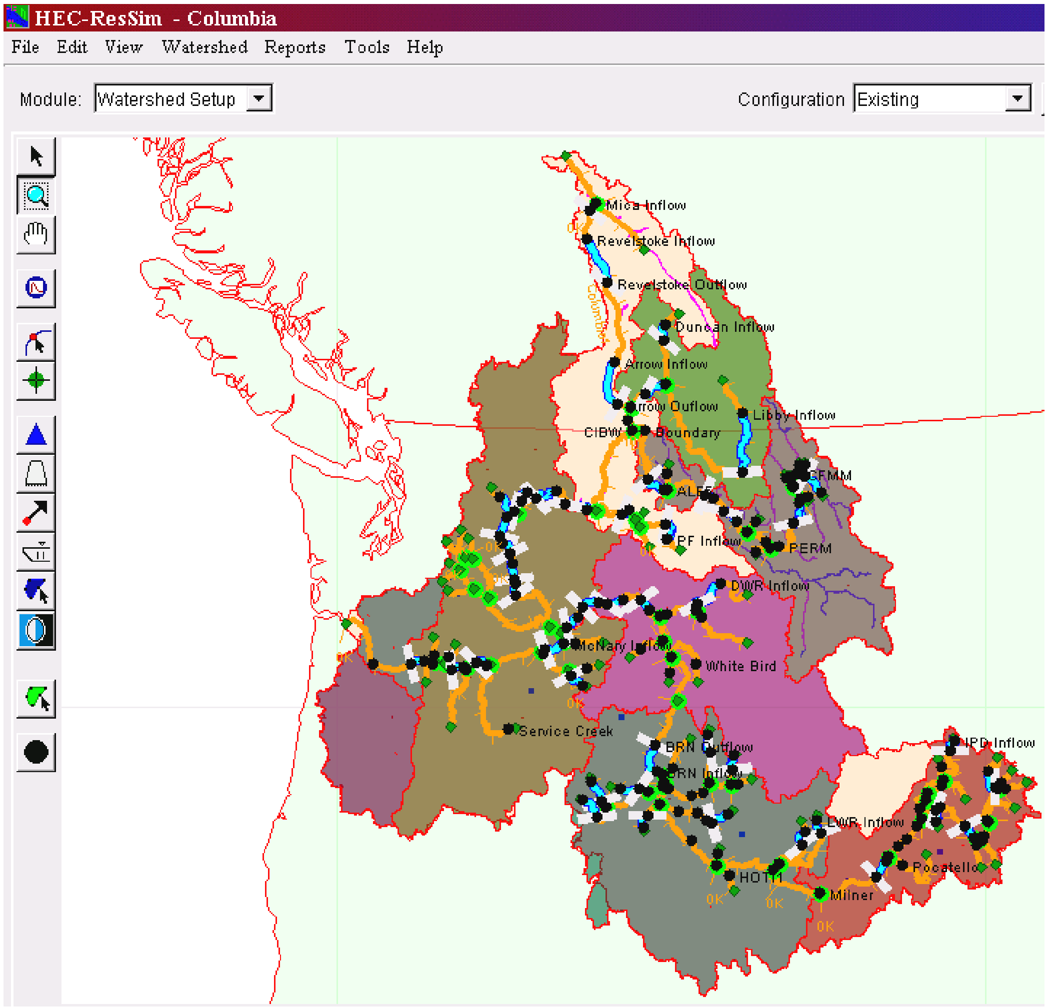


Figure 3. Watershed Setup Columbia River Basin RESSIM Model

The stream alignment was created based utilizing the river, forecast point, and project layers (Figure 4). It was drawn upstream to downstream starting with the mainsteam, then the major tributaries and then minor tributaries. Stream nodes were automatically created when defining a stream element. In addition to stream alignment elements were also added to the watershed. These elements are reservoirs and common computation points. Common computation points are locations where time-series information are exchanged between computer programs. Common computation points include inflow and outflow to a reservoir, stream junctions, diversions, and control points. The common computation points mirrored the NWSRFS model and were gleaned from the appropriate project layers. In the future, these layers could be used for impact areas.

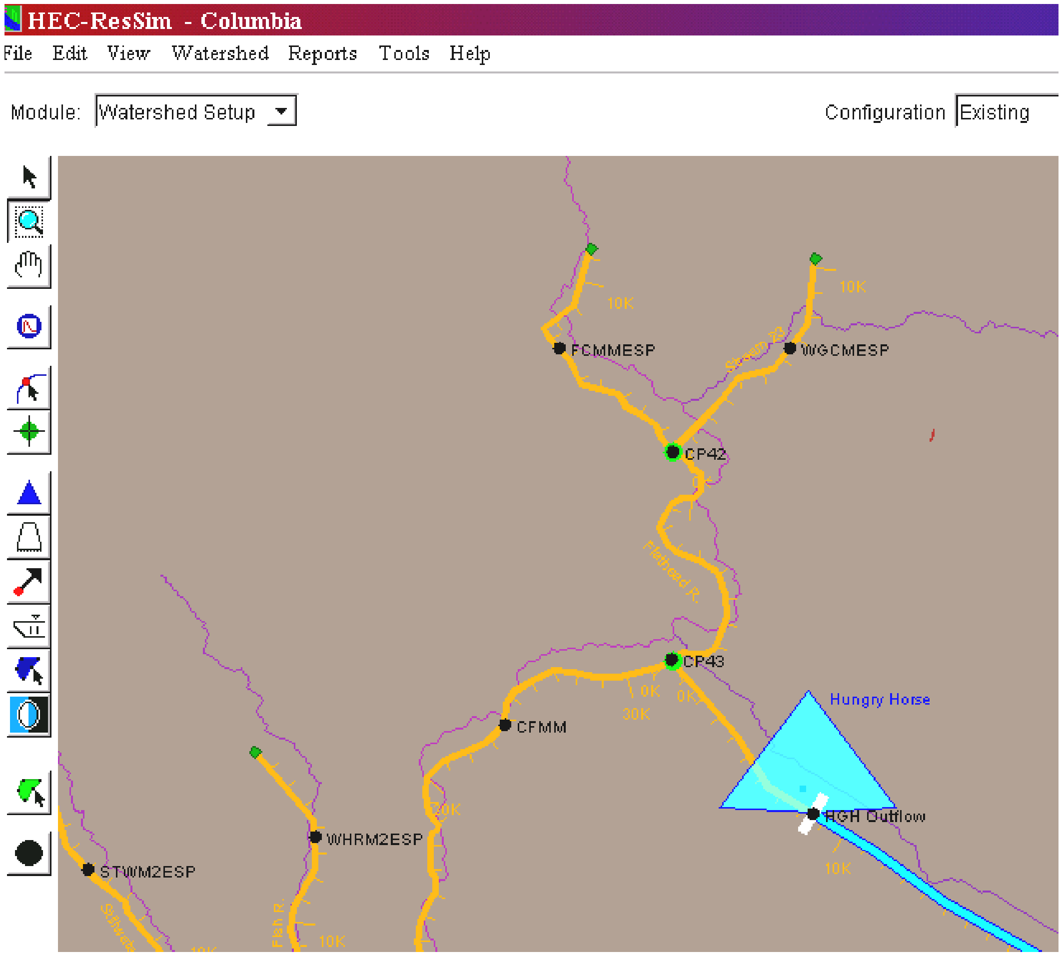


Figure 4. Stream Alignment Columbia River Basin RESSIM Model

Next the watershed was configured. The configuration is based on the physical arrangement of the projects and common computation points and mirrored the NWSRFS model. In the future different configurations will be created to meet the customer, planning, and hydrologic engineering study needs. Once the watershed work was complete, the next step was reservoir network setup.

The reservoir network (Figures 5,6) was created from the watershed configuration. It consisted of element connectivity and element definition. Connectivity consisted of the relationships and definition of reaches, junctions, and reservoirs. It was in the reservoir network setup where physical and operational data associated with the elements were defined and stored. The physical data included rating curves for junctions, routing parameters for reaches, and data for reservoirs.

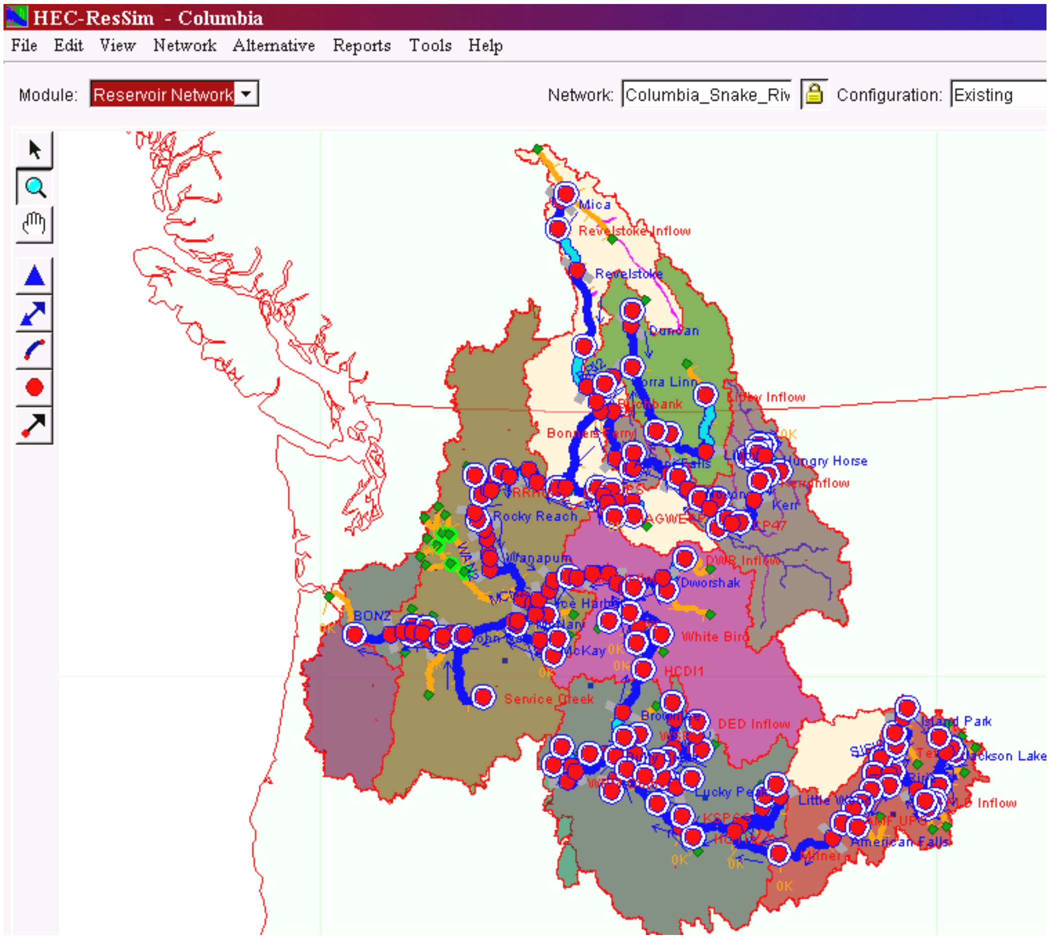


Figure 5. Reservoir Network Columbia River Basin RESSIM Model

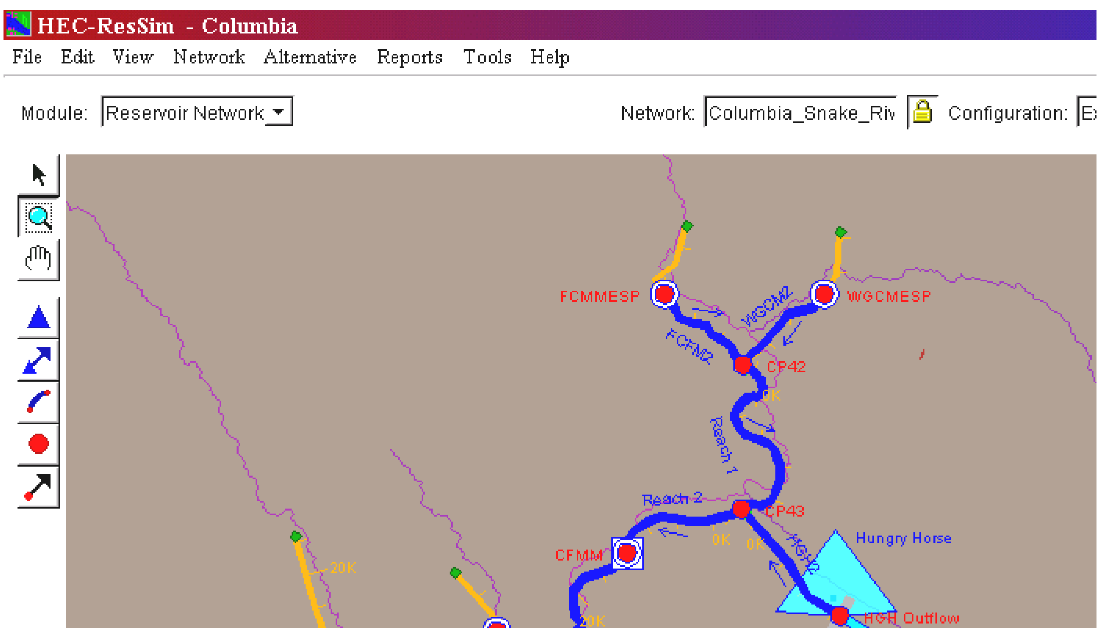
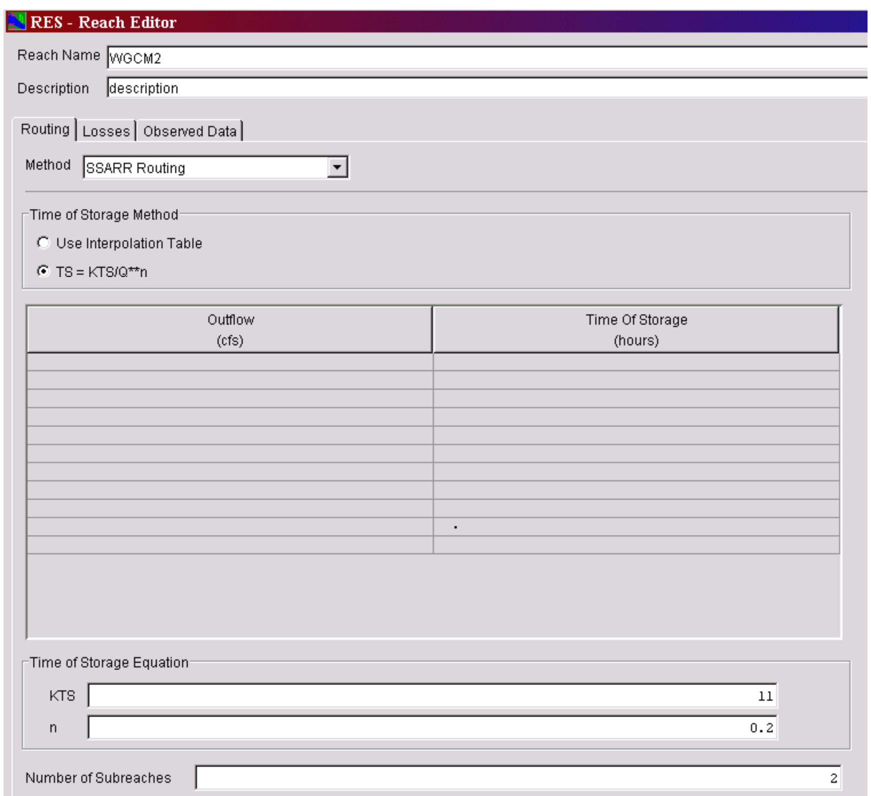


Figure 6. Flathead River Reservoir Network Columbia River Basin RESSIM Model

With respect to defining river reaches, in general many of the routing parameters from the NWSRFS could be used directly (Figure 7). This meant no calibration would have to be done only verification. However during the definition of routing reaches it became apparent that some routings reaches would have to be calibrated due to the nature of stream alignment and more specifically element development.

For example, in SSARR and NWSRFS, river reaches are not defined as graphical stream elements and not necessarily related to stream junction as it is with RESSIM. One could route hydrographs upstream of a stream junction to a control point downstream of the junction without combining the hydrographs at the junction even though it was not physically consistent. One did not have to break up the reaches to include the junction. This is not the case in RESSIM. Junctions must be considered. The reaches as defined with NWSRFS or SSARR would have to be divided into sub-reaches to account for the junctions (Figure 8). Therefore some calibration may be necessary before verification. Data options for junctions included local flow, rating curves, and observed data if needed. Inclusive for local flow are inflows to a reservoir. Since a junction is a common computation point, flows would be added. One nice feature for local flows is the ability apply a ratio factor. This adds some flexibility to the model for what-if scenarios or for corrections to flow forecasts. The default of 1.0 was used in this case.



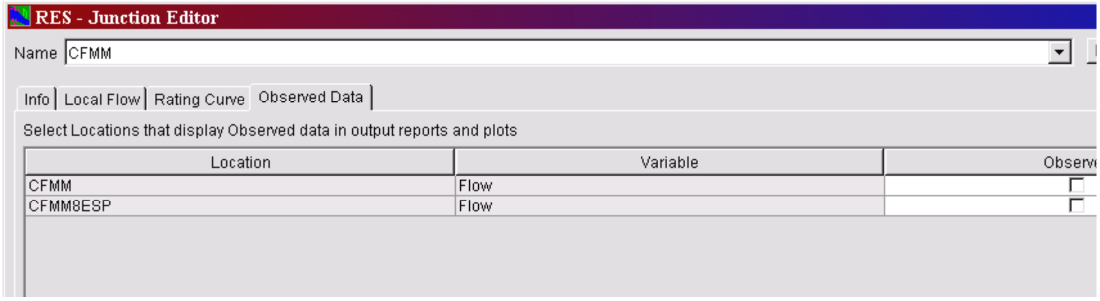


Figure 7. River Reach Editor Columbia River Basin RESSIM Model

Figure 8. Junction Editor Columbia River Basin RESSIM Model

Next physical and operational data were defined for the reservoirs (Figure 9). Physical data include pool, dam, outlet and a composite capacity table. In the future more detail will to define more specific project operations in detail such as hydropower, individual outlets, tailwater rating curves and others. For example for the Hungry Horse project on the Flathead River in Montana, pool and outlet data were defined with a elevation-storage relationship and a composite release capacity curve. Some particularly interesting features to be used in the future include on hourly and daily flow ramp rates and the ability to relate them to rising and falling conditions. With respect to operational zones, data were input for flood control, conservation, and inactive storage zones.

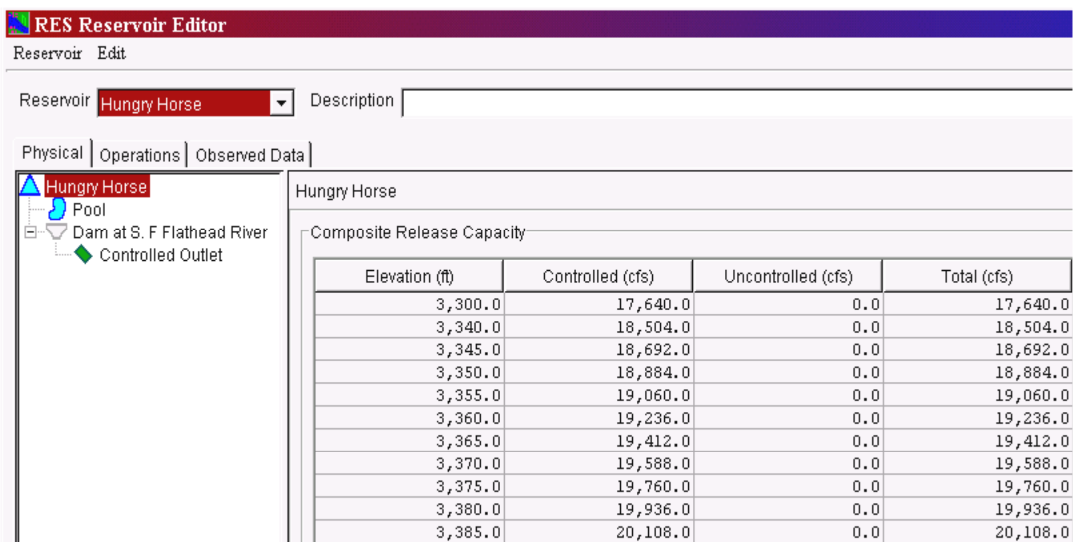


Figure 9. Reservoir Editor Columbia River Basin RESSIM Model

As an example, during Jan-June, Hungry Horse Reservoir on the Flathead River in Montana is operated for local and system flood control while meeting minimum flow requirements out of the project or at the control point, Columbia Falls downstream. For a sample water year, flood control data were specified in terms of target elevations (Figure 10). An intriguing feature of allowing the target elevations to be used on a multi-year basis could be further enhanced by expanding the option to define flood control target elevations for each water year in an historical record. Therefore one could compute a "flood control data set" for each year of an historical record and to be entered under this feature. In addition operational rules were also added for minimum and maximum project releases. For the Hungry Horse control point, Columbia Falls, operational rules were defined for maximum channel capacity (flow) and minimum flow. The operational rule for minimum flow could be enhanced for study purpose if it could be defined on a monthly and water year (historical) basis. Additionally, the operation rule feature would be further enhanced if projects could also be operated to a system flood control point not directly downstream of a project. The rest of the reservoirs were designed in a similar way.

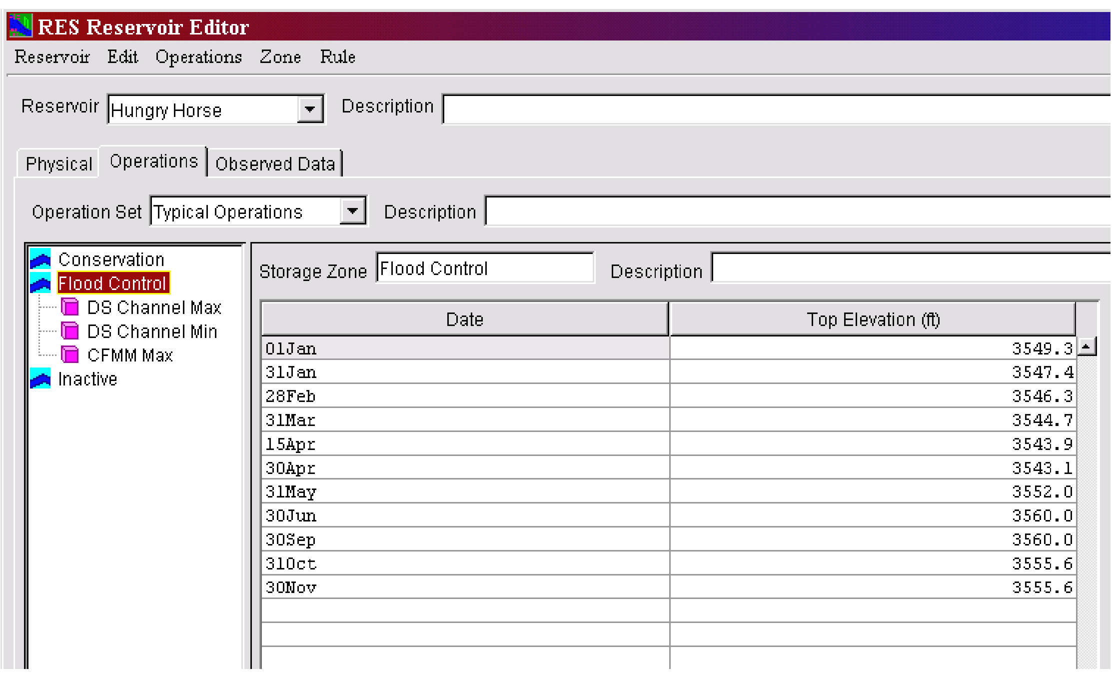


Figure 10. Reservoir Editor Columbia River Basin RESSIM Model

Test simulations to ensure model execution have been performed (Figures 11,12). Calibration and verification are next. After verification, the model will be tested by the Reservoir Control Center in Water Management Division to ensure customer specifications are met regarding process and product. The model will be constantly evaluated for process and product improvement.

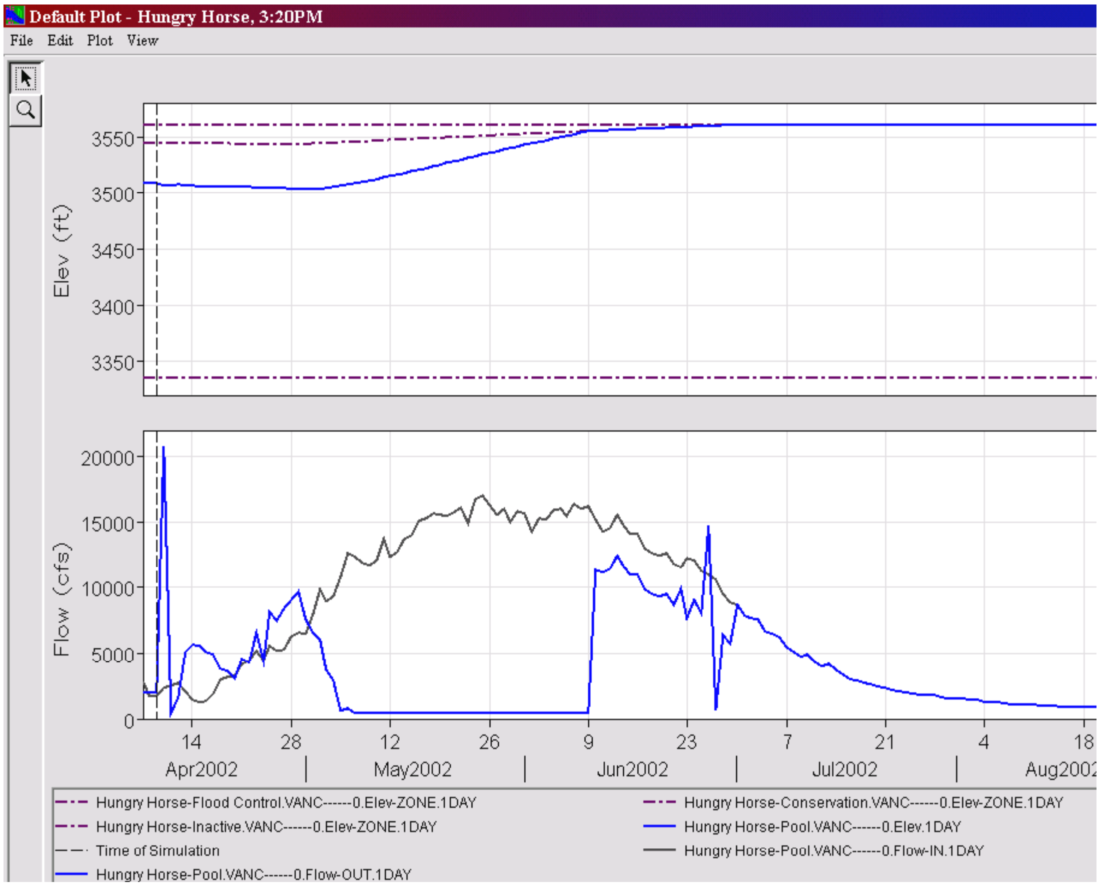


Figure 11. Flathead River at Hungry Horse Reservoir Columbia River Basin RESSIM Model

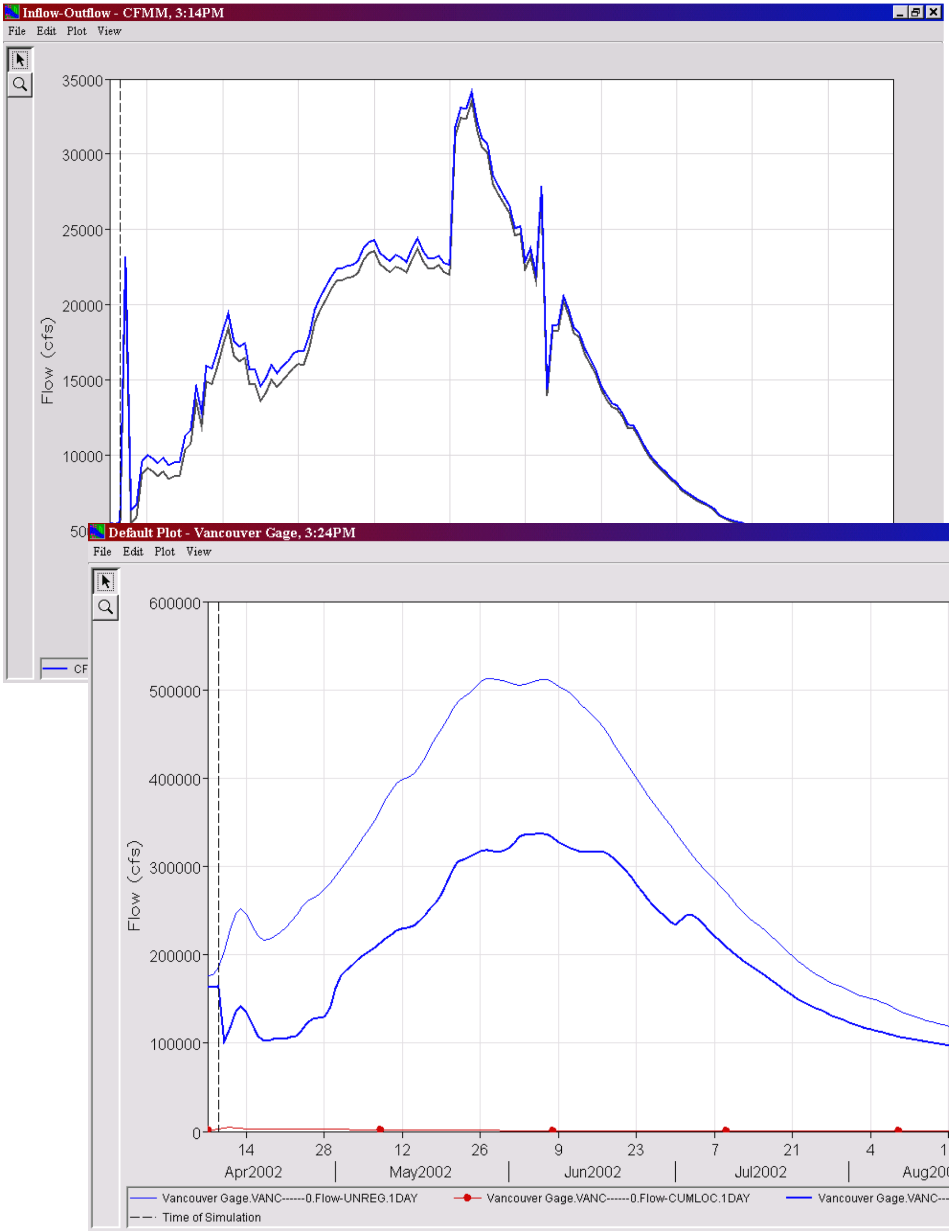


Figure 12. Flathead River at Columbia Falls and Columbia River at Vancouver, Columbia River Basin RESSIM Model

Long-Term

Long-term**,** it is hoped that Water Management will be able to continue to improve the utilization of the RESSIM model. This would be especially true as optimization tools for RESSIM become available; and in-house programs used for planning and flood control studies are converted to work with RESSIM and in the CWMS environment.

With respect to optimization , planned future tools that would augment the RESSIM model are HEC-ResPRM (Corps of Engineers 1996) and HEC-ResFloodOpt (Corps of Engineers 2000). Both utilize linear programming techniques but with different schemes. Utilizing optimization models as a planning tool in conjunction with a simulation model such as RESSIM can potentially provide the user with better information for decision making.

HEC-PRM is a multiple-objective prescriptive reservoir model that works on a monthly time step and analyzes a period of record. It operates on perfect foresight. The program uses linear programming techniques and penalty functions. Values and penalties are assigned to decision variables. These values or penalties are economic or non-economic. Constraints consist of the physical limitations of the system. No routing is performed because of the scheme used. It is a little more restrictive for use than HEC-ResFloodOpt. From a practical standpoint it would be more beneficial if the model were to work on at least a weekly time step. A smaller time step than a week would require routing and, therefore, a different scheme. The program maximizes the total value of the goal objectives of the system and minimizes total penalties. For example, on a system basis, HEC-PRM could be used for a goal of meeting water supply. The program could be used to screen a dataset. This dataset could be a historic dataset or better yet a forecast dataset generated from the NWSRFS ESP model. Potential problematic years could then be simulated with RESSIM. On a headwater basis a model describing multiple purpose objectives could be used to maximize the goals of the project and used as a screening tool for a simulation model.

HEC-ResFloodOpt is model that is descriptive in the short-term. The only objective is flood control. It operates on a one-hour to daily time step for a single event. It operates on perfect foresight. The program uses linear and multiple integer programming techniques. Constraints consist of continuity, diversion, reservoir release, and logical variables. Penalties are assigned to decision variables. The decision variables include reservoir release, reservoir storage, channel flow rates, and diversion rates. The goal is to minimize the objective function in order to minimize damage from flooding. Such a model that could be used for real time flood control operations such as on the Willamette River System in describing a preferred operation. Perhaps utilizing such a flood control optimization model could make the simulation process more efficient by reducing the amount of iterations necessary to "dial" in a flood control operation.

Additionally, Water Management would like merge a disparate group of tools used for flood control and planning studies with RESSIM and CWMS. These tools include spreadsheets, fortran programs run on servers, visual basic programs, and the current SSARR study tool, AUTOREG.

Conclusion

In conclusion, Water Management Division, Northwestern Division will continue to play an important role in the operation of the complex system of multiple-purpose projects in the Pacific Northwest. SSARR has served Water Management superbly. It appears that the new capabilities of RESSM (short- and long-term) in conjunction with NWSRFS and other CWMS models will provide a superior product and allow Water Management Division as well as other Corps offices to be state of the art in water management operations.

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